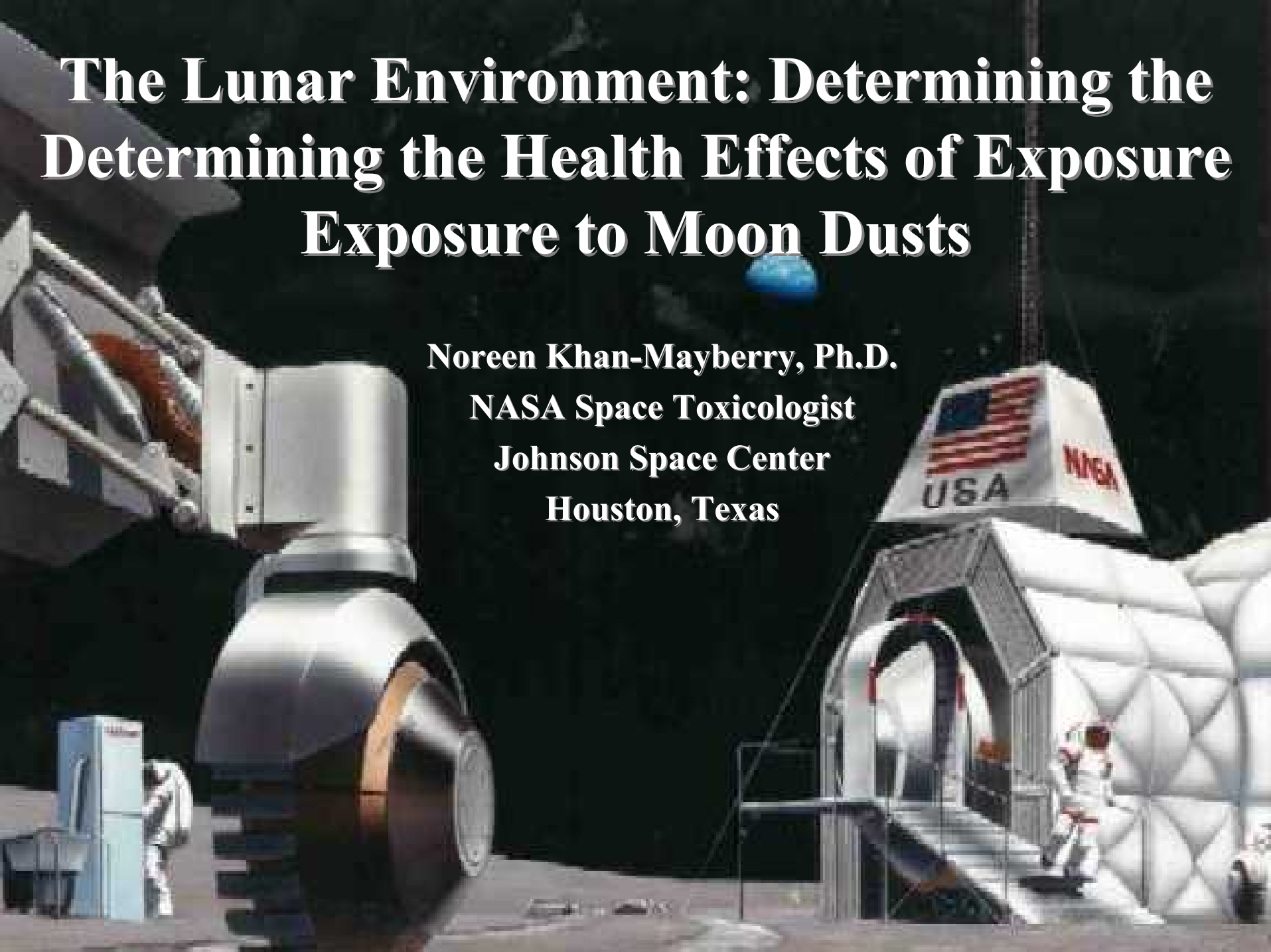
The Lunar Environment: Determining the Determining the Health Effects of Exposure Exposure to Moon Dusts



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The Lunar Surface

The Earth’s moon presents a hostile environment in environment in which to live and work.

There is no atmosphere to protect its surface from the from the ravages of solar wind and micrometeorite micrometeorite impacts.

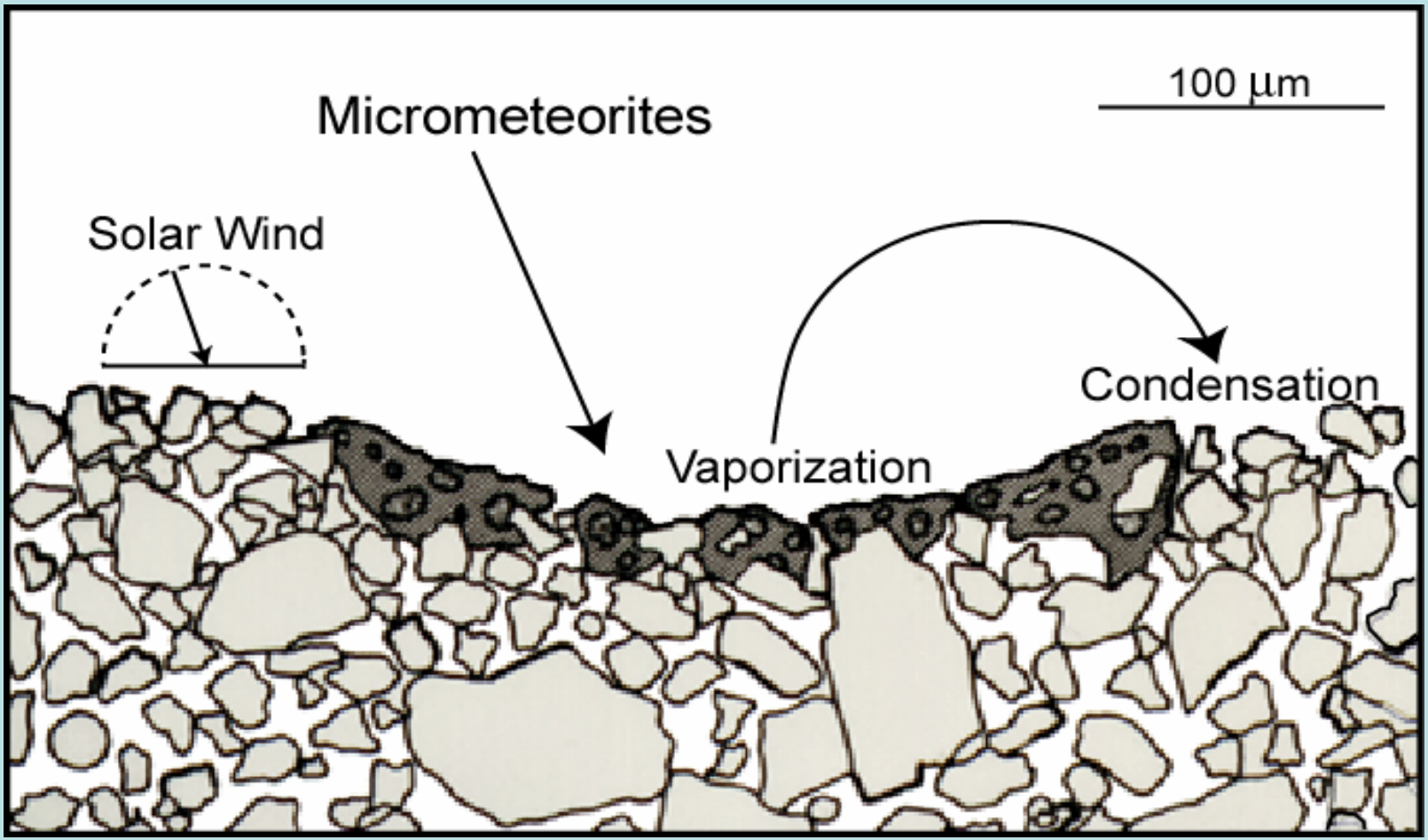
Lunar Airborne Dust Toxicity Advisory Group - *LADTAG*

•To date, no scientifically defensible toxicological studies have been have been performed on lunar dusts, specifically the determination of determination of exposure limits and their affect on human health. human health.

•The multi-center LADTAG (Lunar Airborne Dust Toxicology Toxicology Advisory Group) was formed in response to the Office of the Office of the Chief Health and Medical Office's (OCHMO) request (OCHMO) request to develop recommendations for defining risk defining risk criteria for human lunar dust exposure.

•The LADTAG group, chaired by Dr. John T. James, NASA's Agency NASA's Agency Toxicologist & Dr. Russell L. Kerschmann, ARC ARC Space Life Science Division Chief & board certified pathologist, pathologist, formed a world class group of technical experts in lunar experts in lunar geology, inhalation toxicology, biomedicine, cellular biomedicine, cellular chemistry and biology from within the agency the agency along with the nations' leading external experts in these experts in these fields. Based upon LADTAG's qualified recommendations, our group decided it was prudent to pursue pursue developing a permissible exposure limit standard and human and human health risk criteria.

Lunar Soil Formation



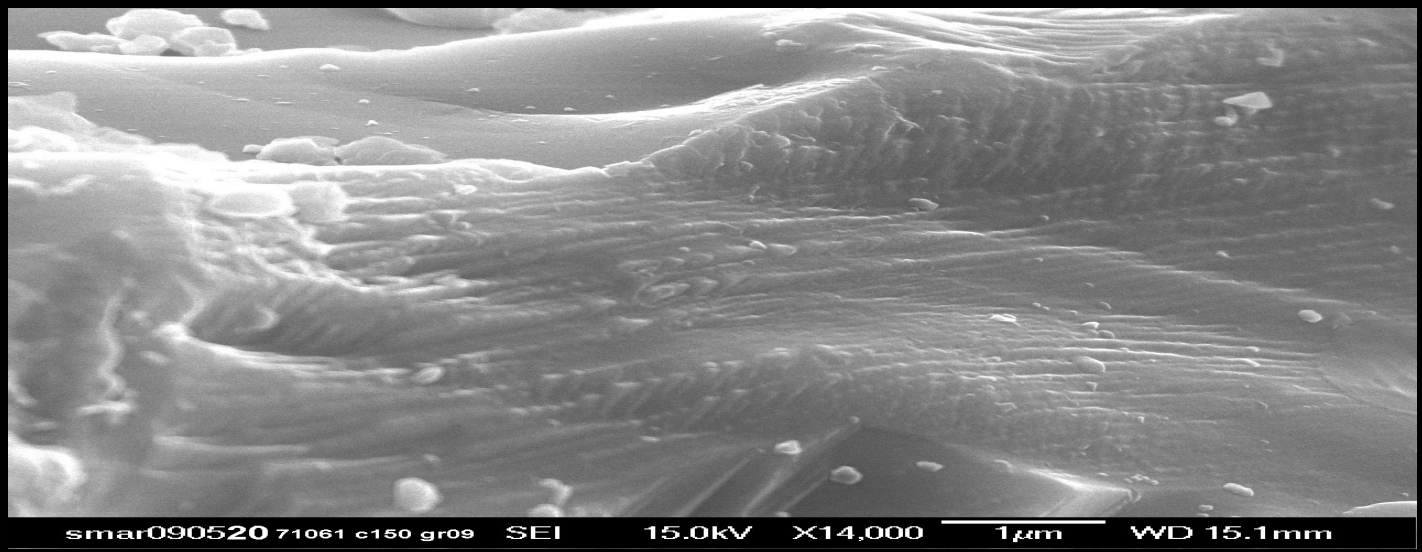
Comminution, Agglutination, & Vapor Deposition

Courtesy Dr. Larry Taylor, U Tenn - Knoxville

Evolution of Lunar Soils

- Terrestrial dusts are weathered to a round shape over time
- Lunar dusts undergo constant impacts of micro-meteorites (no atmospheric atmospheric protection from impacts)
- *Lunar soil is formed by a combination of :
  - Communition by impact processes
  - Agglutination by impact processes
  - Addition of volcanic ash
  - Space weathering (solar particle sputtering and vapor generation and deposition)
  - Mixing including regolith gardening

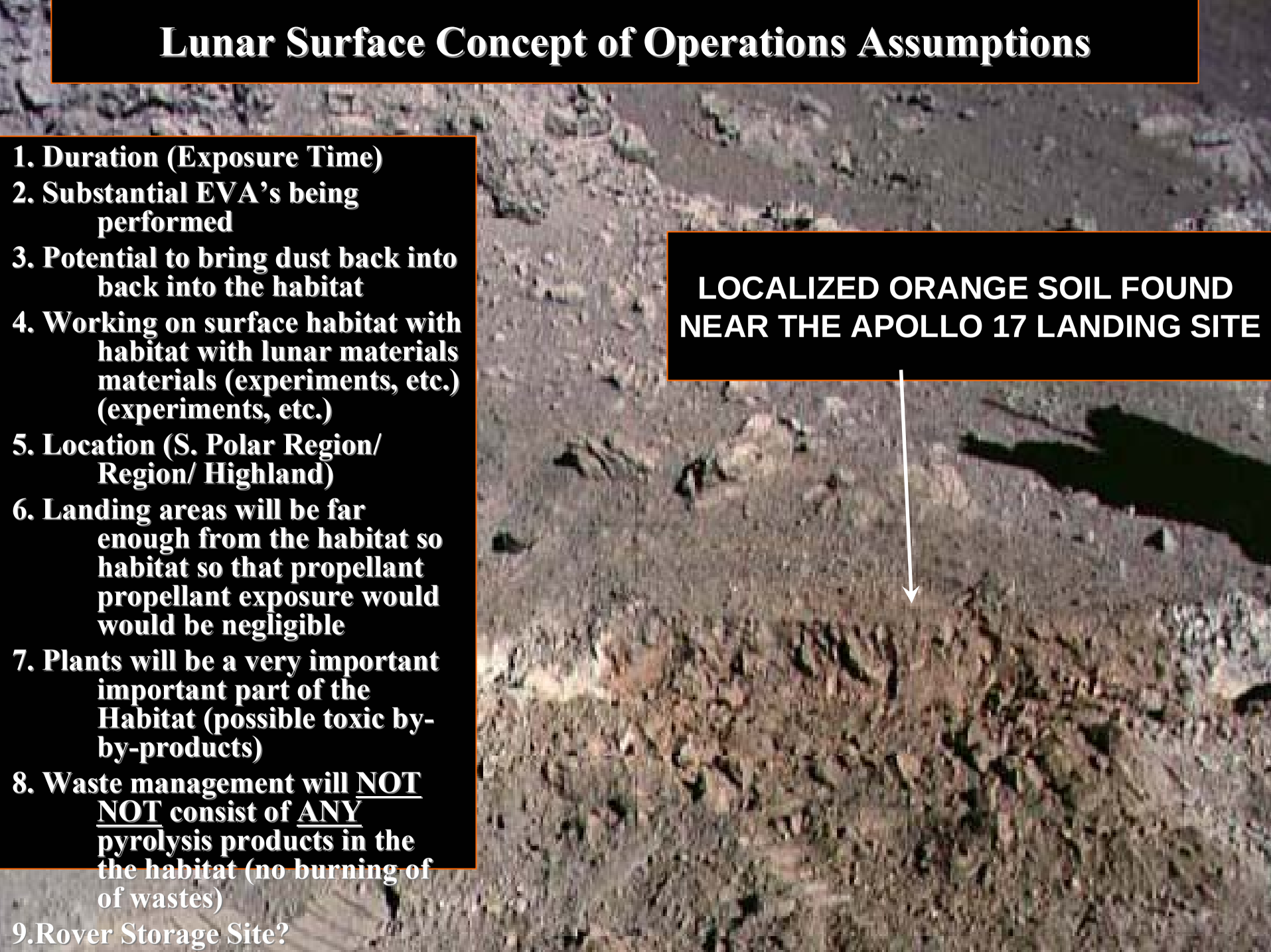
*Grain surface etched by the solar wind; such surfaces have high density of crystal crystal dislocations and are presumably very reactive



*Courtesy: D.M. McKay, NASA (2006)

Lunar Surface Concept of Operations Assumptions

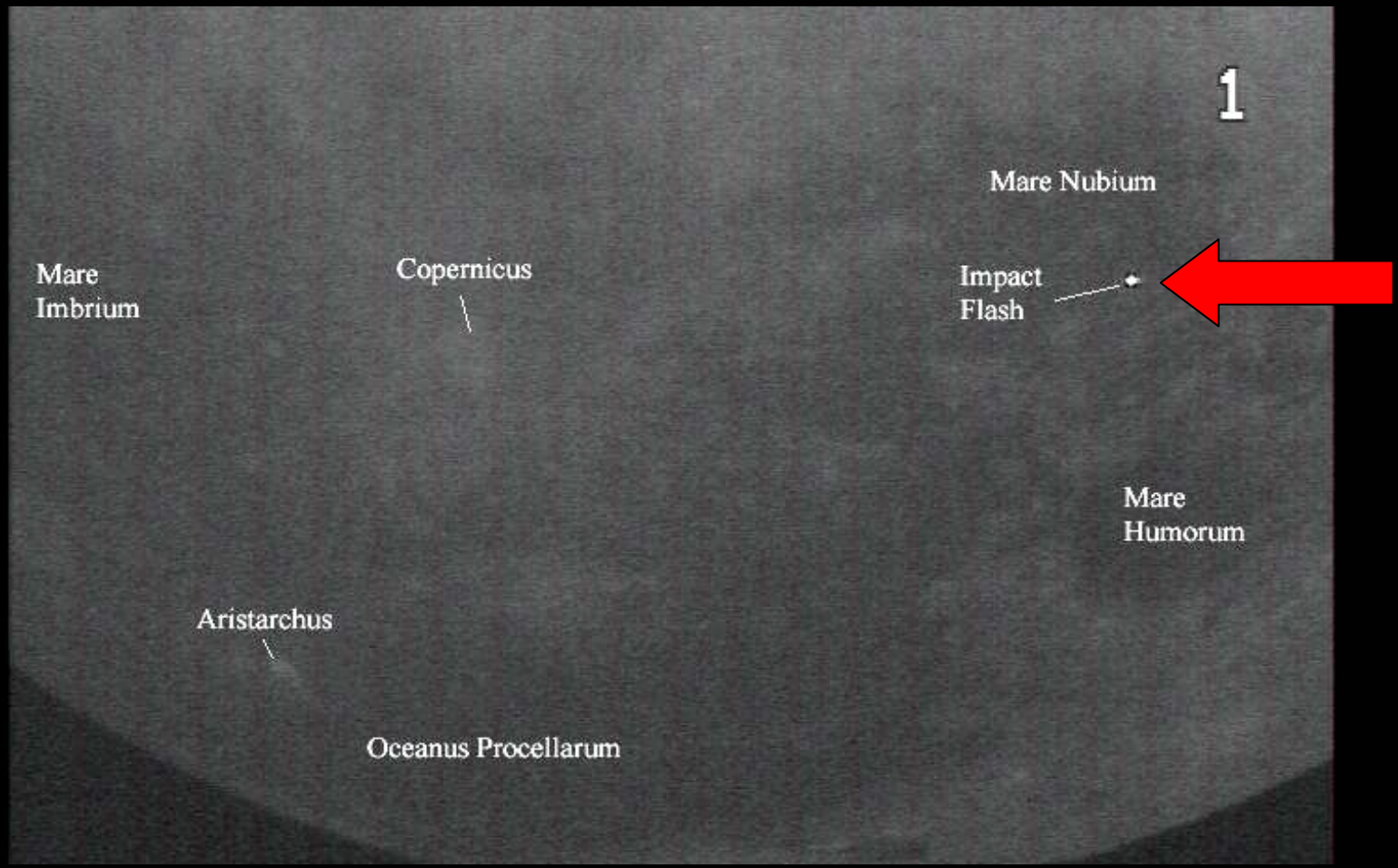
1. Duration (Exposure Time)
2. Substantial EVA's being performed
3. Potential to bring dust back into back into the habitat
4. Working on surface habitat with habitat with lunar materials materials (experiments, etc.) (experiments, etc.)
5. Location (S. Polar Region/ Region/ Highland)
6. Landing areas will be far enough from the habitat so habitat so that propellant propellant exposure would would be negligible
7. Plants will be a very important important part of the Habitat (possible toxic by-by-products)
8. Waste management will NOT NOT consist of ANY pyrolysis products in the the habitat (no burning of of wastes)
9. Rover Storage Site?



What does the Apollo experience tell us?

- Data from Apollo is a starting point – point – looking at suits, filters, vac vac bags, rock box washings (forensic (forensic engineering)
- Low n's
- Some "measure" of exposure (brief, (brief, episodic) & effects (irritancy, (irritancy, "smell" of space)
- Mechanical irritant; may be a chemical irritant
- Mission objectives will be different in different in the future
- Unrealistic to be "dust –free"

Lunar Impact May 2, 2006



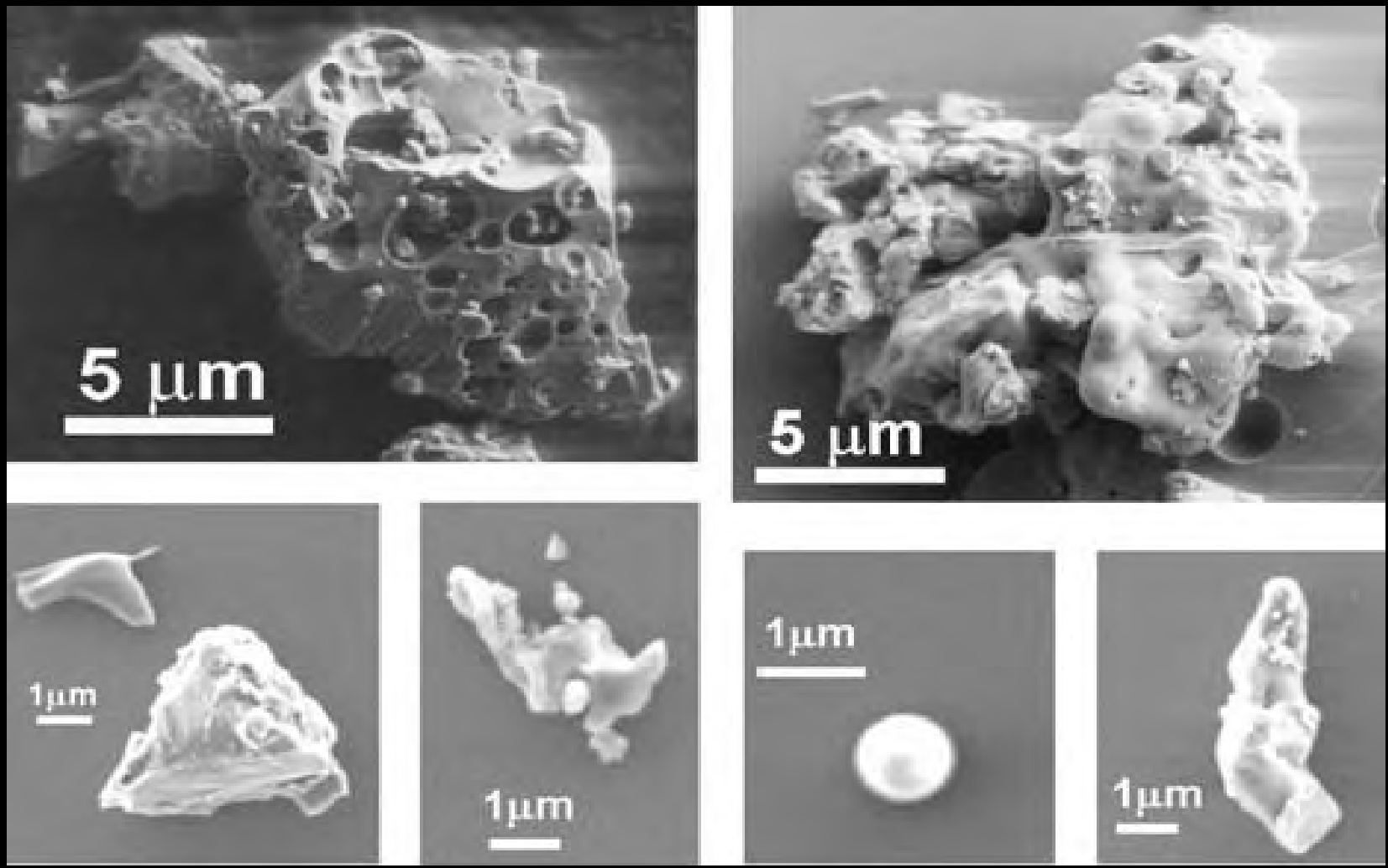
Courtesy: J.T. James, NASA (2005)

The Lunar Surface

The moon's surface is covered with a thin layer of layer of fine, charged, reactive dust capable of capable of entering habitats and vehicle compartments, where it can result in crewmember health problems.

- Approximately 10% of lunar dust is in the respirable range (<10μm).
- Lunar dust has a very large surface area (~8 times (~8 times that of a sphere of equivalent external external size).
- Lunar dust is subjected to potential activation activation processes not found on Earth
  - Solar wind implantation (H_2 implantation → implantation → bubbles throughout dust dust particles)
  - Nanophase Fe on surface
  - Deposition of vaporized impaction-derived derived material
- No known surface passivation mechanism other other than agglutination

What does Moon dust look like?



Courtesy, S.K. Noble, 2006

LADTAG's Logic

•LADTAG research studies are geared towards producing deliverables aimed at *reducing uncertainty* in contributing factors (size distribution, time factors, activity, dose, species)

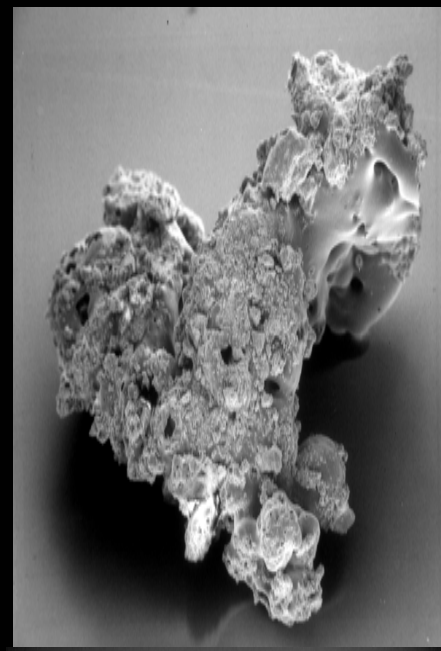
•LADTAG has reviewed the available lunar dust literature and the technical expertise of the advisory group. The group has recommended that in order to set a representative health standard, we must test multiple types of lunar dusts, specifically finest fraction (<10 μm) of lunar dust simulant and the immature and mature highland dust.

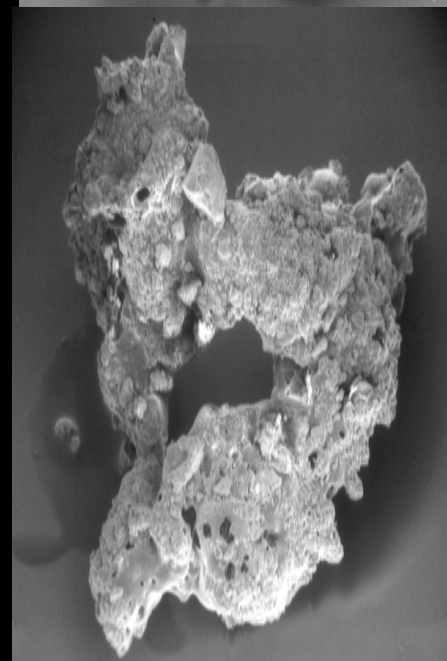
•These highland soils were selected based upon NASA's plan to land in the polar region upon return to the lunar surface.

•This particle size fraction was selected because it is considered to be the respirable size range.

•The respirable fraction has historically been extremely difficult to analyze, yet this data is key for evaluating the toxicological properties of lunar dusts.

• Modern technology has provided several new options for particle size analysis, particularly in this fine size range

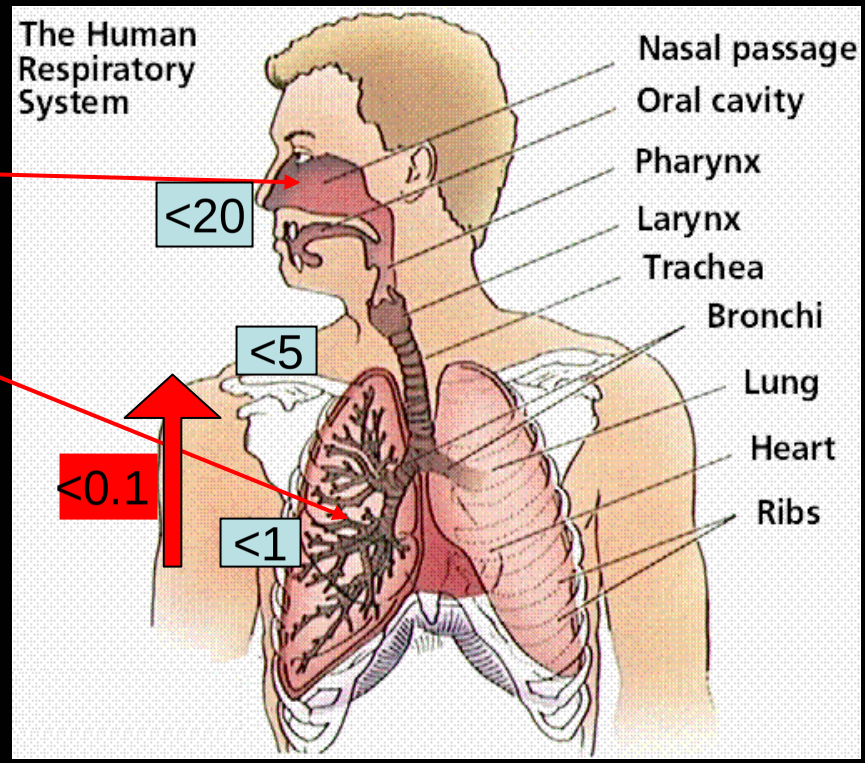




Known Toxic Effects of Dusts

Dusts

- Dermal irritation & penetration
- Eye irritation & corrosion
  - Chemical
  - Mechanical
- Respiratory injury
  - Upper air ways
  - Lower airways
    - Edema
    - Inflammation
    - Fibrosis
    - Cancer?



Courtesy: J.T. James, NASA (2005)

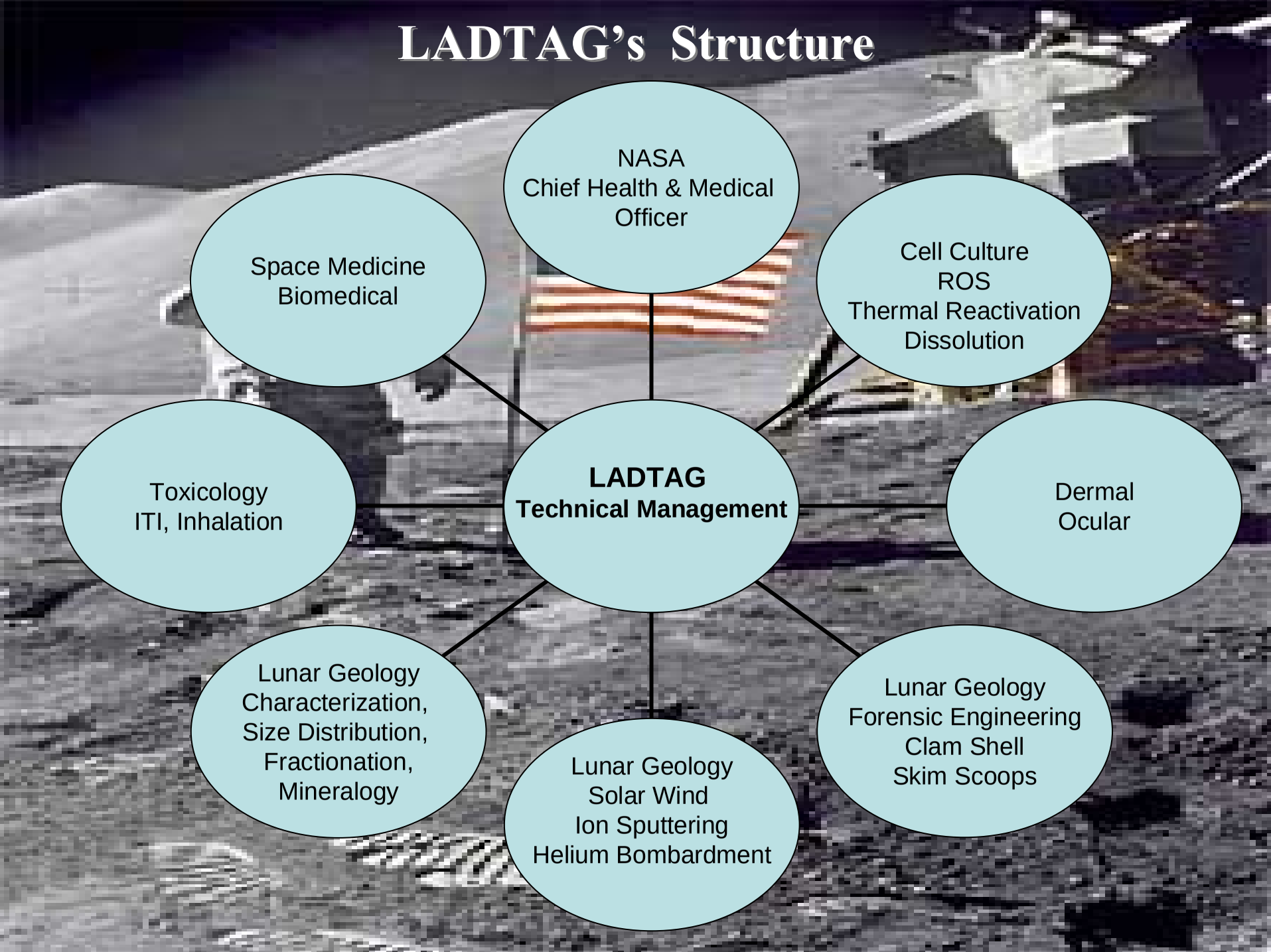
Unknown Toxic Effects of Lunar Dusts

- Dermal irritation & penetration
- Eye irritation & corrosion
  - Chemical?
  - Mechanical?
- Respiratory injury?
  - Lung clearing of unusual particle shape?
  - Effective clearance mechanisms?
  - Effect in 1/6 g?
  - Effect of highly reactive/ activated particles?
  - Effect of inactive particles?
  - Rate of passivation?
  - Effect of nanophase Fe?
  - Cellular injury? Generation of ROS?

LADTAG Plan of Action

- Review data available to set exposure standards for lunar dusts dusts
- Guide/integrate research efforts
- Conduct research to fill data gaps
- Set defensible exposure standards for lunar dusts
  - Brief vs. long-term exposures
  - Highland vs. mare dusts
  - Polar vs. equatorial dusts
  - Activated vs. aged dust
  - Simulants vs. real lunar dusts
- Interface with other groups studying lunar dusts

LADTAG's Structure



LADTAG Research Data Gaps

Lunar Geology:

1. Characterize lunar dust recovered from Apollo hardware
2. Characterize lunar dust from pristine, unfractionated Apollo soils
3. Determine an accurate grain size distribution for major representative lunar soil types
4. Determine mineral and glass phase identification and populations for major representative lunar soil types
5. Provide totally new data on the finest fraction <1 micrometer
6. Activate simulants with hydrogen/proton bombardment and UV in order to compare surface reactivity with non-activated soils
7. Provide well-characterized soil from Apollo hardware, from pristine samples, and from activated samples to toxicology team

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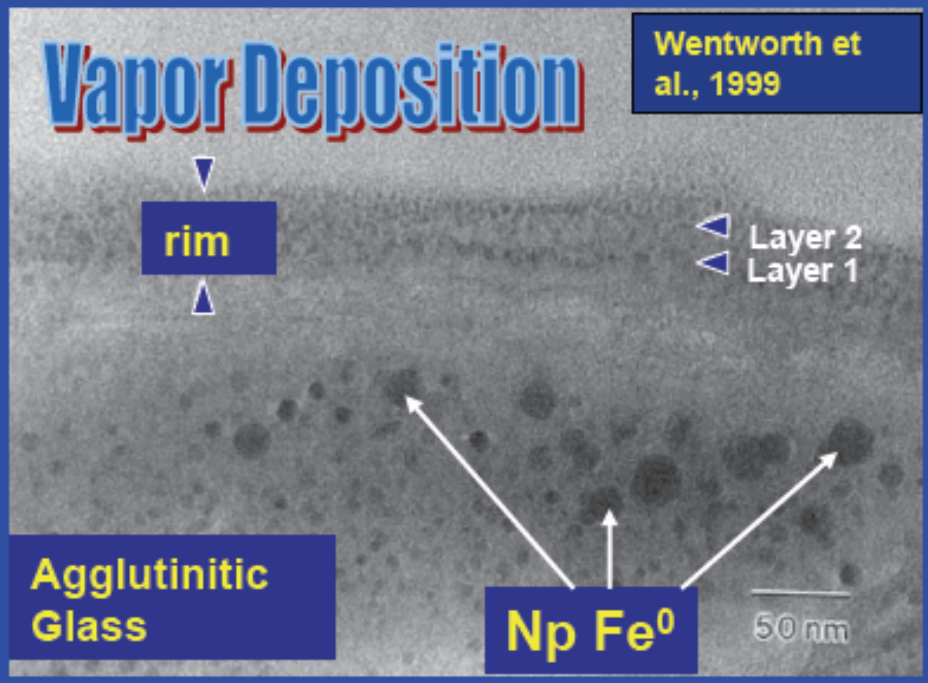
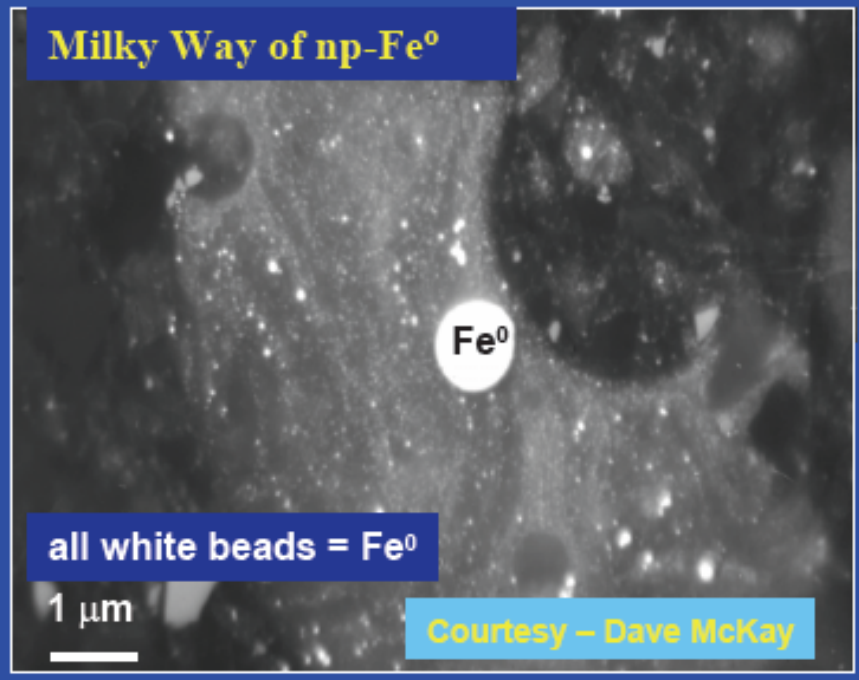
Metallic Fe TOXICITY on Dissolution of Glass ?



TEM Image of Glass Rim



SEM BSE-Image of Mare Agglutinitic Glass

Virtually All Impact Glass Contains Nano-Sized Metallic Fe

LADTAG Research Data Gaps

Activation:

- **Heat Activation (Dry Thermal Cycling)**
- **Rate of Passivation**
- **Simulated solar wind bombardment**

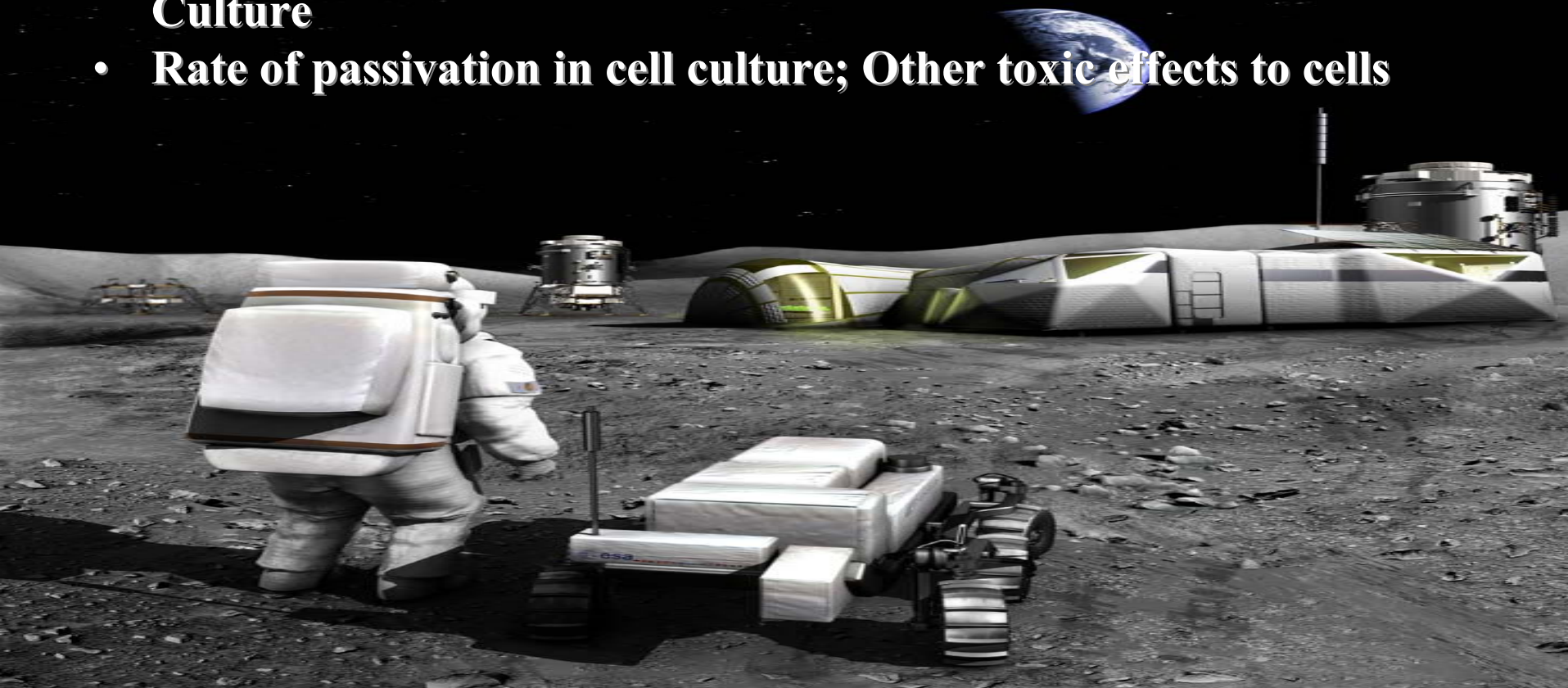
Dissolution:

- **Rate of dissolution in neutral pH**
- **Rate of dissolution in reduced pH (cellular enzymes, lysosomes)**

LADTAG Research Data Gaps

Toxicology:

1. Respiratory - Conduct ITI studies (simulants, lunar dusts)
2. Respiratory - Conduct Inhalation Studies (simulants, lunar dusts)
3. Dermal (simulants, lunar dusts)
4. Ocular (simulants, lunar dusts)
5. Cell Culture
   - Determine if lunar dusts generate Reactive Oxygen Species in Cell Culture
   - Rate of passivation in cell culture; Other toxic effects to cells



LADTAG's Ultimate Deliverable

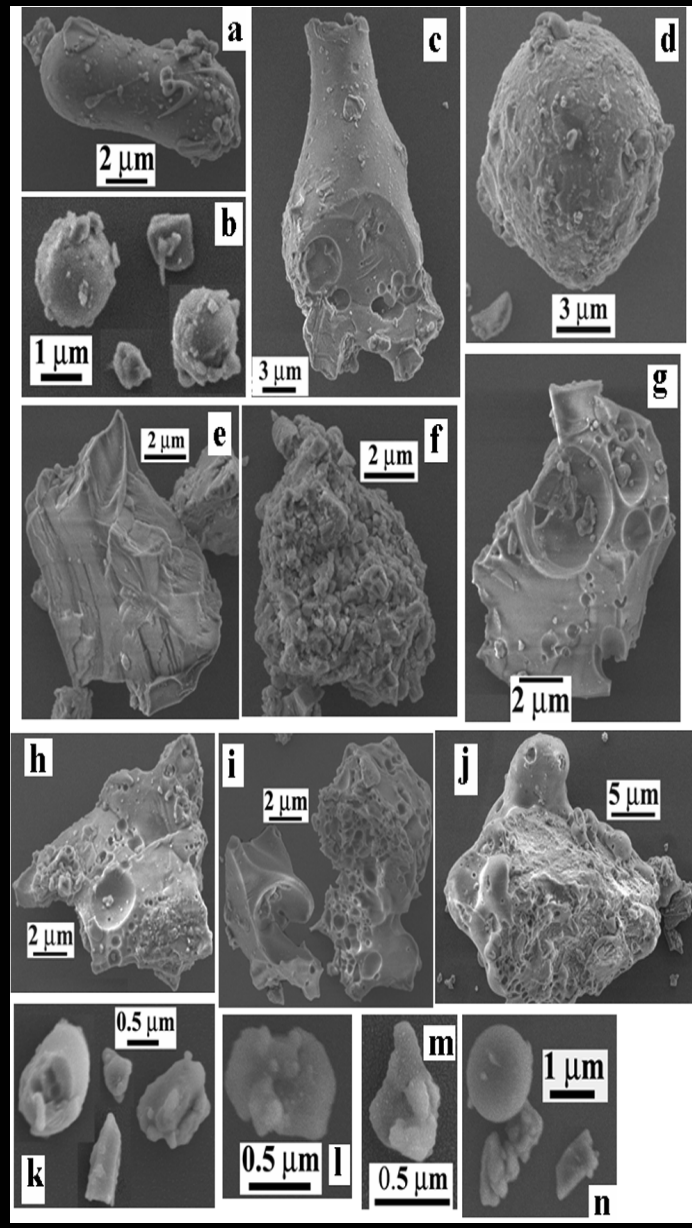
•While LADTAG was primarily concerned with airborne lunar dust, the group is also studying effects of non-airborne dusts on human health

- **•Dermal toxicity (skin irritant/allergic responses, and abrasion effects – *Breach of water barrier?)***
- **•Ocular Toxicity (eye irritant/allergic responses, and abrasion effects – *Scratches, Embedding?)***

•Effects of dissolution of lunar dust on toxicity in human system is being studied

•Development of acute and chronic (time based) exposure limit standards for inhalation (pulmonary) toxicity and human risk criteria will be developed no later than 2010.

•LADTAG does not rule out the development of setting other standards & human health risk criteria based upon findings of non-airborne dust toxicity studies.



Acknowledgements

- Dr. John T. James
- Dr. Russell Kerschmann
- Dr. Chiu-wing Lam
- Dr. Antony Jeevarajan
- Dr. David S. McKay
- Dr. David J. Loftus
- LADTAG Committee Members
- LADTAG Technical Subgroup Members

Questions???